

## Phase II Testing of Liquid Cooling Garments Using a Sweating Manikin, Controlled by a Human Physiological Model

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Previous testing showed the thermal sensation and comfort followed the expected trends as the LCG inlet fluid temperature was changed. The Phase II test data demonstrates the repeatability of ADAM by retesting the baseline LCG. Skin and core temperature predictions using ADAM in an LCG/Arctic suit combination are compared to NASA physiological data to validate the manikin/model. Additional LCG configurations are assessed using the manikin and compared to the baseline LCG. Results can extend to other personal protective clothing, including HAZMAT suits, nuclear / biological / chemical protective suits, and fire protection suits.

# Phase II Testing of Liquid Cooling Garments Using a Sweating Manikin, Controlled by a Human Physiological Model

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**\*\*Note: This draft is very rough as testing was delayed and began the week of March 13<sup>th</sup>. All test results will be compiled and published in the final version of this paper.**

## ABSTRACT

An Advanced Automotive Manikin (ADAM) developed at the National Renewable Energy Laboratory (NREL) is used to evaluate NASA's liquid cooling garments (LCGs) used in advanced space suits for extravehicular applications. The manikin has 120 separate heated/sweating zones and is controlled by a finite-element physiological model of the human thermo-regulatory system.

Previous testing showed the thermal sensation and comfort followed the expected trends as the LCG inlet fluid temperature was changed. The Phase II test data demonstrates the repeatability of ADAM by retesting the baseline LCG. Skin and core temperature predictions using ADAM in an LCG/Arctic suit combination are compared to NASA physiological data to validate the manikin/model. Additional LCG configurations are assessed using the manikin and compared to the baseline LCG. Results can extend to other personal protective clothing, including HAZMAT suits, nuclear / biological / chemical protective suits, and fire protection suits.

## INTRODUCTION

...the LCG is expected to remain the major heat acquisition element for removing heat from the crewmember, and improvements to the LCG are needed to reduce its weight by one-half for planetary missions, and to improve its performance.

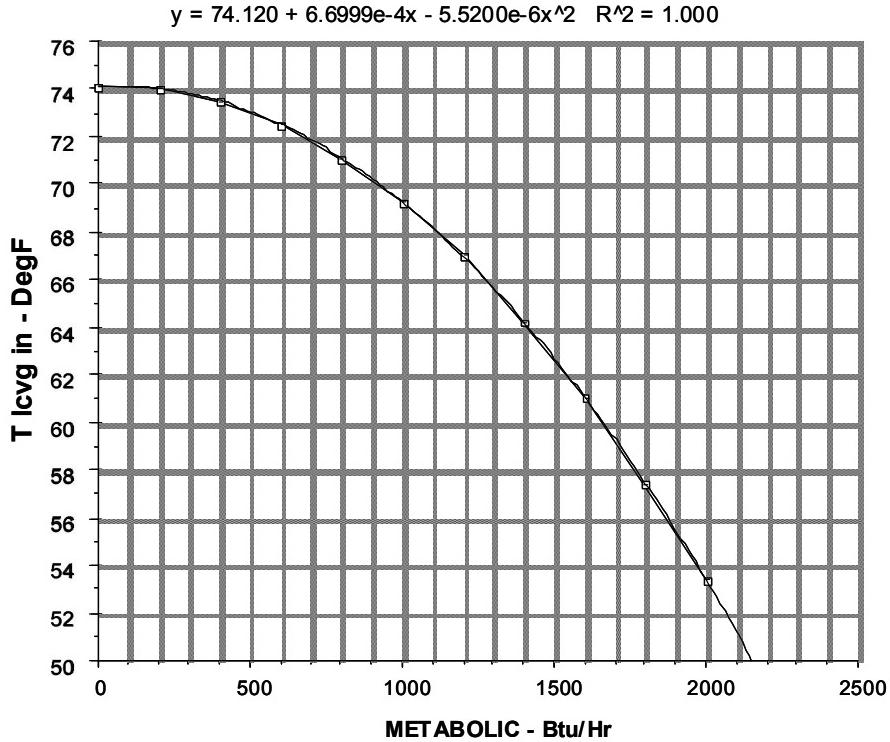


Figure X. Auto Cooling Control Curve

## PHASE ONE TEST SUMMARY

The phase one test objectives for the LCG testing with ADAM were to:

1. Validate the ADAM manikin and model by comparing data from this test to physiological data generated from previous NASA testing
2. Assess the manikin/model capability to test LCGs
3. Gather baseline data for the LCG
4. Test a cooling vest concept for performance comparison to LCG.

## PHASE TWO TEST OBJECTIVES

The phase two test objectives for liquid cooling garment testing with ADAM were to:

1. Repeat the baseline tests from the phase one tests to demonstrate repeatability
2. Test the LCG with an arctic suit to minimize losses to the environment and better simulate the EMU condition
3. Test the Orlan LCG with an arctic suit for performance comparison
4. Gather data to validate the ADAM manikin and model, and compare this data to physiological data generated from previous NASA testing. This can be achieved by simulating test conditions from a previous LCG test and comparing ADAM's response to the physiological data.

## PHASE TWO TEST ARTICLES

### LCVG

The LCVG is a conformal undergarment that covers the body from the neck to the wrists and ankles. Water flows through the LCVG flexible tubing to remove excess metabolic heat from the crewmember, and oxygen is vented from the helmet down to the hands and feet for further cooling.



Figure 1. LCG on ADAM

*Insert pics of LCG*

#### **Orlan LCVG**

The Orlan LCVG is the Russian-designed cooling garment. It is also a conformal undergarment that covers the body from the neck to the wrists and ankles, and also includes cooling for the head. Water flows through the flexible tubing to remove excess metabolic heat from the crewmember.

*Insert pics of Orlan LCG and Orlan LCG on ADAM*

*Insert information and pics of Arctic Suit*

Descriptions/pictures of the following:

- ADAM

#### **Environment Test Chamber**

Several improvements have been made to the environmental chamber since the Phase One testing. The room has had a dedicated Heating, Ventilation, and Air Conditioning (HVAC) system installed to provide humidity, temperature control, and air recirculation that is independent of the rest of the building. A heating coil can supply 5000W of heating capacity, and a cooling coil using building chilled water supplies cooling to the room. A dual output Fuji PID Microcontroller simultaneously adjusts heating and cooling supply levels based on the temperature control set-point. The control system was designed to maintain temperatures between 15°C and 38 °C. Temperature input to the controller is obtained from a thermocouple suspended in the center of the room. A Carnes steam humidifier is used to regulate humidity. A Fuji PID Microcontroller adjusts steam injection into the HVAC duct as required by the humidity set-point. The humidity can be controlled between approximately 20% and 100% depending on the room temperature set-points. A portable dehumidifier is available when high building humidity makes achieving the lower humidity levels difficult. Humidity input to the controller is obtained from a capacitance style humidity sensor suspended in the center of the room. The HVAC system has a 250 CFM blower that circulates air within the room. Air is exhausted into the room along two sides of the ceiling directed down along the walls. The air return is at 1 foot above the floor in one corner of the room. Typical air flow velocity in the middle of the room where the manikin is positioned is approximately 0.1m/sec.

In practice, relative humidity can be controlled to +/- 1%, and temperature surveys have shown less than 0.1°C variation from floor to ceiling in the center of the room.

In order to provide repeatable cooling for the LCG, a Neslab water chiller was installed. This unit can provide up to 2500W of heat removal, and maintain +/- 0.1° C temperature stability. Chilled water flow through the LCG is measured by a Dwyer Model TF1053 flow sensor. Temperature into and out of the LCG is monitored by thermocouples in the fluid stream as close to the LCG as possible. A series of valves is used to throttle the output of the chiller pump to a flow of 1.8 l/min through the suit.

A data acquisition system comprised of a laptop computer, and National Instruments hardware collects room temperature, humidity, chilled water flow rate, and water inlet/outlet temperatures.



Figure 2. Humidifier



Figure 3. Fluid Connection



Figure 4. Flow System



Figure 5. Chiller

#### **TEST PROCEDURE (these bullets will be filled in as the test is completed)**

- Environmental conditions: chamber temperature and humidity
- Thermocouple Type and where located, calibration and data logging
- Room size, temp/humidity controllers, air velocity
- ADAM power, comm., chamber hoist lift
- LCG placement on ADAM, sweat rates for segments, segment temperatures
- How the physiological model works

#### **TEST RESULTS**

##### ***LCG Baseline Tests***

- Repeat Phase 1 tests to prove repeatability with ADAM

CASE 1. LOW METABOLIC RATE OF 200 W WITH A COOLANT INLET TEMPERATURE OF 22.2°C (72°F)

*Test Results TBD*

CASE 2. HIGH METABOLIC RATE OF 350 W WITH COOLANT INLET TEMPERATURE OF 19.5°C (68°F)

*Test Results TBD*

CASE 3. AVERAGE METABOLIC RATE OF 275 W WITH VARIED COOLANT INLET TEMPERATURES (17.78°C [64°F], 19.5°C [70°F], and 24.44°C [76°F])

*Test Results TBD*

**LCG with arctic suit**

- Evaluate performance of LCG and ADAM comfort with arctic suit cover to minimize losses to the environment and better simulate the EMU condition

CASE 1. LOW METABOLIC RATE OF 200 W WITH A COOLANT INLET TEMPERATURE OF 22.2°C (72°F)

*Test Results TBD*

CASE 2. HIGH METABOLIC RATE OF 350 W WITH COOLANT INLET TEMPERATURE OF 19.5°C (68°F)

*Test Results TBD*

CASE 3. AVERAGE METABOLIC RATE OF 300 W WITH VARIED COOLANT INLET TEMPERATURES (15°C [59°F], 20.6°C [69°F], and 26.11°C [79°F])

*Test Results TBD*

CASE 4. LOW METABOLIC RATE OF 200 W WITH A COOLANT INLET TEMPERATURE OF 16.7°C (62°F)

*Test Results TBD*

CASE 5. HIGH METABOLIC RATE OF 350 W WITH A COOLANT INLET TEMPERATURE OF 25.6°C (78°F)

*Test Results TBD*

**Orlan LCG with arctic suit**

- Evaluate performance of the Orlan LCG and ADAM comfort with arctic suit cover to minimize losses to the environment and better simulate the EMU condition; compare this data to the EMU LCG

CASE 1. LOW METABOLIC RATE OF 200 W WITH A COOLANT INLET TEMPERATURE OF 22.2°C (72°F)

*Test Results TBD*

CASE 2. HIGH METABOLIC RATE OF 350 W WITH COOLANT INLET TEMPERATURE OF 19.5°C (68°F)

*Test Results TBD*

CASE 3. AVERAGE METABOLIC RATE OF 300 W WITH VARIED COOLANT INLET TEMPERATURES (15°C [59°F], 20.6°C [69°F], and 26.11°C [79°F])

*Test Results TBD*

CASE 4. LOW METABOLIC RATE OF 200 W WITH A COOLANT INLET TEMPERATURE OF 16.7°C (62°F)

*Test Results TBD*

CASE 5. HIGH METABOLIC RATE OF 350 W WITH A COOLANT INLET TEMPERATURE OF 25.6°C (78°F)

*Test Results TBD*

**ADAM Validation**

- Gather data to validate the ADAM manikin and model, and compare this data to physiological data generated from previous NASA testing. This can be achieved by simulating test conditions from a previous LCG test and comparing ADAM's response to the physiological data.

## **CONCLUSIONS**

This report presents results for the second series of tests using ADAM as a tool to evaluate LCGs for exploration space suits...

## **FUTURE WORK**

## **ACKNOWLEDGMENTS**

We'd like to thank the Academy...

## **REFERENCES**

## **CONTACT INFORMATION**

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John Rugh, M.S.M.E., leads the vehicle ancillary loads reduction task at NREL. The objective of the project is to reduce fuel used for vehicle ancillary loads by reducing thermal loads, improving delivery efficiency, and increasing equipment efficiency including using engine waste heat to provide cabin cooling. He can be reached at John\_Rugh@nrel.gov.

Luis Trevino is a part of the Advanced Extravehicular Activity Team at the NASA Johnson Space Center. He is the Thermal Subsystem manager for the development of the next generation Portable Life Support Systems that will be used with the Lunar and Martian space suits. He can be reached at luis.trevino-1@nasa.gov.